Stability and Yield of Cool-Season Pasture Grass Species Grown at Five Irrigation Levels

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ABSTRACT

The yield stability of cool-season pasture grasses at different irrigation levels has not been well documented. Objectives were to evaluate selection of pasture grass species in environments where irrigation may be limited or unreliable. Dry matter yield was determined for eight grass species during 1996 through 1998 at five irrigation levels. Shukla's stability statistics were calculated and species selection based on mean-yield versus Kang's yield-stability indices were compared. Tall fescue (*Festuca arundinacea* Schreb.), meadow brome (*Bromus riparius* Rehm.), and orchardgrass (*Dactylis glomerata* L.) had higher than average dry matter yield and were selected on a mean-yield basis. On the basis of Shukla's statistics, meadow brome and orchardgrass did not contribute to the genotype × irrigation level interaction or the genotype × irrigation level × year interaction, respectively. Perennial ryegrass (*Lolium perenne* L.) also did not contribute to these genotype × environment interactions; however, Shukla's statistics suggested that the linear effect of irrigation was the underlying determinant of perennial ryegrass's apparent stability. Species selection based on yield-stability indices were generally in close agreement to selection of species on a mean-yield basis. One exception, Kang's Modified Rank Sum method, placed too much emphasis on stability resulting in selection of species with low forage yields. Tall fescue had superior forage yield at all irrigation levels and was always selected by yield-stability indices. Orchardgrass and meadow brome were also selected by all yield-stability indices. These results indicate that tall fescue, orchardgrass, and meadow brome are the species of choice where irrigation may be limited.

During the past decade, there has been a resurgence in the use of pasture and grazing systems in the USA. In the West, the opportunity for reducing equipment and operating costs and new land policies restricting grazing on public lands has led to increased interest in maximizing production on irrigated pastures. The use of cool-season grass pastures by western livestock producers would be impossible, in many instances, without irrigation (Burns and Bagley; 1996, p. 344). Most cool-season pasture grass cultivars were developed in more humid regions than the semiarid region of the Intermountain West. These grasses usually perform adequately in the semiarid environment when sufficient irrigation water is available. However, drought occurs on a regular basis and growing urbanization has created increased demands on western water supplies. This makes the dependability of irrigation water often erratic, especially later in the growing season or during drought years.

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While forage textbooks often describe the relative drought tolerance of grass species (Barnes et al., 1995; Moser et al., 1996), the literature is nearly void of references comparing dry matter yield (DMY) of various grass species at different irrigation levels. Recently, two papers have examined yield potential of cool-season pasture grasses under various irrigation levels (Asay et al., 2001; Jensen et al., 2001). In evaluating tall fescue, Asay et al. (2001) found a significant cultivar × irrigation level interaction. In a separate evaluation, Jensen et al. (2001) found an interaction with irrigation levels within and across orchardgrass and perennial ryegrass cultivars. Jensen et al. (2001), also reported the mean DMY across irrigation levels and years for orchardgrass, perennial ryegrass, tall fescue, meadow brome, smooth brome (*Bromus inermis* Leyss.), and RS hybrid (*Elymus hoffmanni* Jensen & Asay); however, they did not examine or compare the stability of these species across years and irrigation levels.

The risk of producing grass on irrigated pastures can be reduced by choosing grass species that have a high average yield and are more stable when less than optimum irrigation conditions exist. Numerous stability parameters have been developed (Lin et al., 1986), but their use in selecting high-yielding, stable genotypes has been limited (Kang, 1993). Shukla's (1972) stability-variance statistic (σ_i^2) measures each genotype's relative contribution to a significant genotype × environment (GE) interaction. Lin et al. (1986) classify Shukla's stability statistic within the agronomic concept of stability, where σ_i^2 is a test of a particular genotype's parallelism to the mean response pattern over environments of all evaluated genotypes. A significant σ_i^2 indicates that a genotype's performance was unstable across environments (Shukla, 1972). In addition, Shukla's (1972) formulas provide for the use of covariates to remove heterogeneity from the GE interaction and partition the remainder GE interaction into variances (s_i^2) contributed by each genotype (Magari and Kang, 1993). A significant s_i^2 indicates that the genotype was still unstable following the removal of the linear effect of the covariate (Magari and Kang, 1993). The use of covariates, which can be any environmental factor such as humidity, precipitation, temperature, or environmental index, allows researchers to investigate possible causes of GE interactions.

Plant breeders and agronomists often ignore GE interactions and usually select genotypes on the basis of their mean performance across environments, especially when all the test environments fall within some defined target environment. Combining yield performance with yield stability across environments has received very little practical use (Kang, 1993), but could be advantageous when the target environment encompasses a wide range of environmental conditions. Kang (1993) showed that selecting for yield and stability will not automatically result in lower yield. On the other hand, under poor environmental conditions, the use of unstable, high yielding genotypes can result in crop failures (Kang, 1993).

Kang (1988) developed the rank-sum method (KRS) that combines yield and Shukla's σ_i^2 statistic to rank genotypes for selection. This selection index assigns equal weight to yield and stability by ranking genotypes for yield (highest to lowest) and σ_i^2 (lowest to highest), and then summing the two rankings (Kang, 1988). The KRS index was found to be useful in simultaneously selecting for yield and stability (Kang et al., 1991; Kang and Pham, 1991). A modified rank-sum (KMRS) method was developed that placed a greater penalty on instability by adjusting yield rank according to the significance level of σ_i^2 (Kang, 1991). This was accomplished by assigning a stability rating of 0 for nonsignificant σ_i^2, and -8 and -4 for σ_i^2 significant at $P = 0.01$ and 0.05, respectively, and summing yield rank with the stability rating. Bachireddy et al. (1992) compared KRS and KMRS and found that KMRS selected sweet corn (*Zea mays* L.) genotypes with a mean yield closer to that selected by yield alone, but also selected more unstable genotypes than KRS. Kang developed the YS_i yield-stability statistic to show the consequences of making Type I or Type II errors in genotype selection (Kang, 1993). This statistic consisted of modifying the KMRS method by adjusting yield rankings in accordance to how many LSD units a genotype's yield is greater or less than the overall mean yield. It also incorporated a stability rating of -2 when σ_i^2 is significant at the $P = 0.1$ level (Kang, 1993). Magari and Kang (1993) and Pazdernik et al. (1997) found the YS_i statistic was useful in selecting high-yielding, stable corn and soybean [*Glycine max* (L.) Merr.] genotypes, respectively. They did not compare the YS_i statistic with the KRS and the KMRS methods.

In this study, eight cool-season grass species were evaluated for forage yield under five levels of irrigation with a line-source irrigation system. Intensive grazing management was simulated by repeated clipping. The overall objective was to determine which species can be categorized as high yielding and stable, and therefore, should be recommended to growers for use in intensively grazed pastures where irrigation may be limited. This was accomplished by (i) examining species × irrigation level interactions, trends, and stability, (ii) determining if water received at each irrigation level was the main underlying source of species × irrigation level interactions, and (iii) comparing species selected on a DMY-alone basis versus those selected by Kang's KRS, KMRS, and YS_i yield-stability indices.

MATERIALS AND METHODS

Eight grass species were evaluated for their forage yield stability across different years and irrigation levels with a line-source sprinkler system. Each species was represented by one or two cultivars or breeder populations. These included the following: brome hybrid—an experimental brome hybrid developed by Agriculture and Agri-Food Canada, Saskatoon, Canada (*B. inermis* × *B. riparius*); 'Matua' rescuegrass (*B. catharticus* Vahl); 'Fleet' and 'Regar' meadow brome; 'Ambassador' orchardgrass; 'Zero Nui' and 'Bastion' perennial ryegrass; RSH—an experimental line from our program and 'Newhy' RS hybrid [*Elytrigia repens* (L.) Nevski × *Psuedoroegneria spicata* (Pursh) A. Love] (recently described as *Elymus hoffmanni* Jensen & Asay); BR-3—an experimental line from Agriculture and Agri-Food Canada, Saskatoon, Canada and 'Manchar' smooth brome; and 'Forager' and 'Fawn' tall fescue.

The data used in this paper were collected simultaneously with the tall fescue experiment of Asay et al. (2001). Plots were established in 1995 at the Utah State Univ. Evans Experimental Farm near Logan, UT (41°45′ N, 111°8′ W, 1350 m above sea level). The soil at this site consisted of a Nibley silty clay loam series (fine, mixed mesic Aquic Argiustolls). Plots consisted of six drilled rows 15 cm apart and 15 m long, and were planted perpendicular and on both sides of a line-source irrigation pipe. The plots were planted with a cone seeder at a rate of approximately 135 seeds per linear meter. Alley ways parallel to the sprinkler were mowed at 3-m intervals leaving five 1- by 2-m plots, each representing a different irrigation level. The plots were fertilized using 56 kg N ha^{-1} in midsummer and fall of 1995, prior to the first harvest and after Harvests 2, 4, and 6 in 1996 and 1997; and prior to the first harvest and after Harvests 2, 4, and 5 in 1998.

Forage yield was measured during 1996, 1997, and 1998 at the five different irrigation levels. Plots were harvested to a stubble height of 8 cm with a sickle-bar mower six different times in 1996 and 1997 and five times in 1998. The first harvest occurred when tall fescue was at the boot stage, and subsequent harvests were made when tall fescue regrowth height was 25 to 30 cm. It is possible that some species were not harvested at the optimum plant development stage to allow for maximum regrowth.

Plots were watered uniformly in 1995 as needed for establishment, and with the line-source sprinkler during 1996 through 1998 to establish a gradient across irrigation levels (IL). Water received at each IL was monitored as the irrigation treatment plus the natural precipitation from first to last harvest. In 1996, some data on water received prior to June were lost and the growing season total was not available. However, the same weekly irrigation schedule (50 mm per week for IL-1) was used all three years. In addition, all three years had nearly identical slopes when water received vs. irrigation level was plotted; therefore, it is assumed that the 1996 water-received totals were similar to 1997 and 1998. The amounts received for IL 1 through 5, respectively, were 886, 766, 611, 525, and 373 mm in 1997; and 817, 702, 570, 499, and 350 mm in 1998.

Plots were arranged as a modified strip-plot design with four replications and irrigation levels applied as nonrandomized strips. Species × environment interactions were tested by analyzing yearly dry matter yield (DMY) across years and irrigation levels as a split-plot in time (Steel and Torrie, 1980) by means of the GLM procedure (SAS Institute Inc., 1999). Because irrigation levels were not randomized within species in the line-source sprinkler system, there was no valid test for the main effect of irrigation level (Hanks et al., 1980). Species, species × IL, species × year, and species × IL × year were tested on the basis of their respective interaction with replication as error terms. Linear, quadratic, and cubic DMY trends due to IL were determined for each cultivar by orthogonal polynomials with unequal intervals (Gomez and Gomez, 1984), and with the 1997-1998 average water received at each IL to compute coefficients. The REG procedure of SAS (SAS Institute Inc., 1999) was used to compute the appropriate

Table 1. Analysis of variance for dry matter production of cool-season pasture grass species grown for three years at five irrigation levels. Species × environment interactions are partitioned into heterogeneity and residual.

Source	df	Significance†
Species	**7**	***
Species × irrigation level	**28**	***
Heterogeneity	**7**	**
Residual	**21**	**
Species × year	**14**	***
Heterogeneity	**7**	**NS**
Residual	**7**	**
Species × environment‡	**98**	***
Heterogeneity	**7**	**
Residual	**91**	**

** Indicates significance at $P = 0.01$.
*** Indicates significance at $P = 0.001$.
† Heterogeneity and residual only tested at the 0.05 and 0.01 probability levels.
‡ Environments are based upon 15 combinations of irrigation level and year. Species × irrigation level × year was significant (df = 56; $P <$ 0.001).

regression equations, as determined by significance of orthogonal polynomial trends, for species × IL.

Stability across IL was analyzed with IL as environments and the species × replication × IL mean of each species as the raw data for analysis. The data were resubjected to analysis of variance to obtain a new pooled error. Shukla's (1972) σ_i^2 and s_i^2 stability statistics, and Kang's (1993) YS_i statistic were calculated for each species by the QBASIC version of STABLE (Kang and Magari, 1995). Environmental index was used as a covariate to remove the heterogeneity from the species × IL interaction and calculated as $(\overline{X}_{.j} - \overline{X}_{..})$, where $\overline{X}_{.j}$ is the mean of all genotypes in the jth environment and $\overline{X}_{..}$ is the overall mean. A comparison of species selection was made between selection for yield alone, and the KRS, KMRS, and YS_i indices. Species with DMY $>$ than the overall mean DMY, or index values $>$ than the mean index value were labeled as selected on mean-yield or yield-stability indices basis, respectively.

Overall stability was examined considering each combination of year and IL as an independent environment (e.g., five IL and 3 yr = 15 environments). Stability analyses followed the procedure outlined for IL. Year to year stability was investigated in manner similar to stability across IL with species × replication × year means as raw data and the previously described analyses.

RESULTS AND DISCUSSION

Producers in water-limited environments would prefer to use high-yielding pasture species that perform consistently from year to year, respond to favorable irrigation levels, and produce some threshold amount of forage under less favorable irrigation levels. The ANOVA for DMY (Table 1) indicated that species × IL, species × year, and species × IL × year interactions were all significant. These significant interactions suggest that it would be more appropriate to base pasture species selection on a combination of yield and yield stability than on mean yield alone.

Species Stability and Selection across Irrigation Levels

The response of species to IL was of primary importance in this study. DMY averaged across years for each IL is reported in Table 2. Meadow brome and perennial ryegrass responded in a linear fashion to decreasing irrigation amounts, while all other species had significant curvilinear (quadratic) responses (Table 2; Fig. 1).

Plotting the appropriate regression equations indicated that the significant curvilinear responses to IL occurred where a species reached its maximum threshold irrigation level and DMY leveled off and/or began to decline. For tall fescue and orchardgrass, this maximum threshold irrigation level was near IL-2 (73 cm) (Fig. 1a; Table 2). RS hybrid, smooth brome, and brome hybrid reached this point near IL-3 (59 cm) (Fig. 1b; Table 2). This clearly confirms that the DMY-potential of these more drought-tolerant species is not equal to that of tall fescue, orchardgrass, and meadow brome in environments where water is not limited. However, the lack of a sigmoid-type curve for any species suggests that our lowest irrigation level (only natural precipitation) was not water limiting enough to show where yield potential approached zero. We would expect that near or at this point, the drought-tolerant species fitness and yield potential would be superior to those of the other species. Matua brome had the highest maximum irrigation level threshold with DMY leveling off near IL-1 (85 cm) (Fig. 1b). The presence of threshold IL for these species suggests that water conservation may be practiced while still maintaining high DMY. The linear responses of meadow brome and perennial ryegrass indicate that irrigation amounts exceeding 85 cm would result in additional DMY. However, their linear responses were not significantly different from each other ($P = 0.249$) (SAS Institute, 1999, analysis of covariance), making the higher-yielding meadow brome the species of choice when DMY is the selection criterion.

Shukla's stability tests found that meadow brome and perennial ryegrass were stable across IL and did not contribute to the species × IL interaction (Table 3), or in other words, their response was parallel to the overall mean response. Interestingly, these are the two species without a significant curvilinear response. Analysis using environmental index as the covariate resulted in a significant s_i^2 for perennial ryegrass (Table 3). The environmental index, for IL, is likely comprised mostly of the linear effect of irrigation level. This, and the change in significance between the σ_i^2 and s_i^2 estimates, indicates that the linear effect of irrigation was the cause of perennial ryegrass's stability. From these results, we might also hypothesize that perennial ryegrass would have been unstable without supplemental irrigation. In comparison, the linear effect of irrigation was not the underlying cause of meadow brome's stability as evidenced by a nonsignificant s_i^2 value. The results for tall fescue, meadow brome, orchardgrass, Matua brome, brome hybrid, and smooth brome are in sharp contrast to those for perennial ryegrass. These species all had significant σ_i^2 values, but nonsignificant s_i^2 values (Table 3) indicating that their instability, or deviation from paralleling the mean response, was due to the linear effect of irrigation.

RS hybrid was the most drought-tolerant species included, and we expected it to be stable across IL. RS

Table 2. Mean annual dry matter production of eight grass species grown under five irrigation levels from 1996 to 1998.

Species	No. of cultivars	Irrigation levels (mm)† 851	734	590	512	361	Mean	S_p^2§	Orthogonal trends‡ Linear	Quadratic	Cubic
		Mg ha^{-1}							% of sum of squares		
Tall fescue	2	21.7	22.5	20.4	18.3	15.1	19.6	8.85	85.5***	12.1**	2.4NS
Meadow brome	2	19.8	18.5	17.7	16.5	14.2	17.3	4.52	96.5***	2.3NS	0.7NS
Orchardgrass	1	19.8	19.8	17.7	15.8	11.8	17.0	11.16	90.0***	9.7**	0.3NS
Matua brome	1	18.0	17.2	15.4	12.9	7.8	14.3	16.88	90.8***	9.0***	0.0NS
Brome hybrid	1	15.2	15.5	15.0	12.8	11.2	13.9	3.49	80.3***	13.7**	2.3NS
Smooth brome	2	13.5	13.7	12.7	12.6	10.6	12.6	1.51	82.2***	15.3*	0.0NS
RS hybrid	2	11.8	11.9	12.0	12.0	9.7	11.5	1.00	45.1**	47.4**	6.8NS
Perennial ryegrass	2	13.6	12.4	10.5	9.5	7.1	10.6	6.43	99.2***	0.7NS	0.0NS
LSD (P = 0.05)		1.6	1.6	1.2	1.1	1.0	1.0				

* Indicates significance at $P = 0.05$.
** Indicates significance at $P = 0.01$.
*** Indicates significance at $P = 0.001$.
† Average amounts of water received from irrigation treatment plus natural precipitation during the growing seasons of 1997 and 1998.
‡ Percentage of irrigation level sums of squares due to orthogonal polynomial trends.
§ Phenotypic variance of each species across irrigation levels.

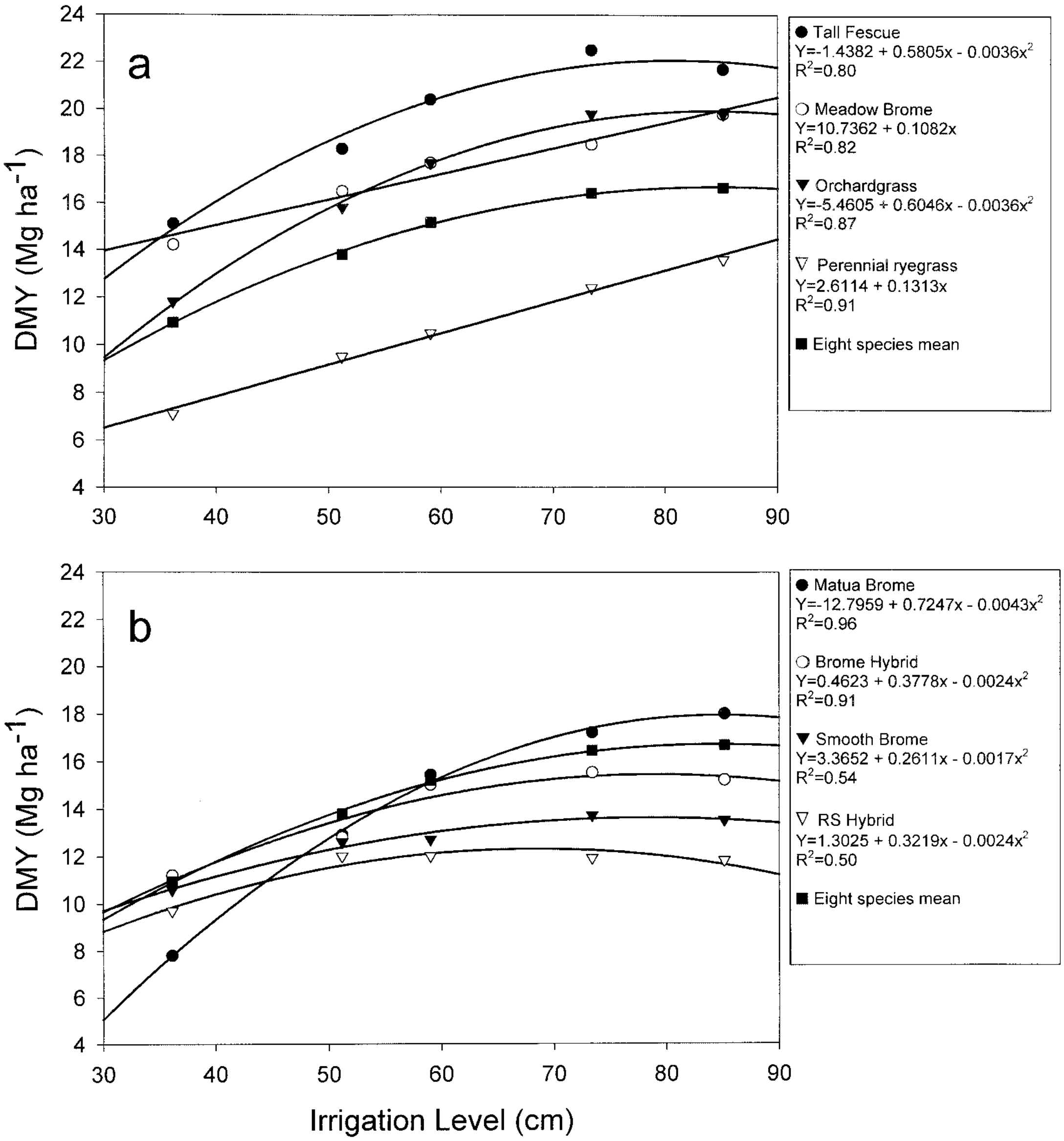

Fig. 1. Yearly mean (1996–1998) dry matter yield (DMY) response of eight cool-season grass species to five irrigation levels. Two plots are shown (a) standard pasture species and (b) less typical and/or more drought tolerant pasture species. The eight species average DMY is plotted in both graphs to aid in comparison. Only perennial ryegrass and meadow brome did not have a significant curvilinear response.

Table 3. Dry matter production stability analysis on eight pasture grass species grown 1996 to 1998 at five irrigation levels. Stability parameters are Shukla's (1972) stability-variance statistic (σ_i^2) and stability-variance statistic following removal of heterogeneity from species × environment interaction due to environmental index (s_i^2).

	Across irrigation levels†		Across all environments‡		Across years§	
Species	σ_i^2	s_i^2	σ_i^2	s_i^2	σ_i^2	s_i^2
Tall fescue	1.8917**	1.0150NS	37.1681**	33.1218**	46.3516**	19.9481**
Meadow brome	0.3959NS	1.0417NS	13.1575**	14.4573**	14.3157**	22.5051**
Orchardgrass	4.4165**	−0.0338NS	3.9013NS	1.9796NS	−2.3973NS	−1.4524NS
Matua brome	15.6686**	0.0120NS	62.7791**	65.3492**	66.2938**	13.1007**
Brome hybrid	1.5128*	1.0920NS	5.9375**	6.0448**	5.9340**	15.0401**
Smooth brome	6.3687**	0.3075NS	5.4150**	2.3281NS	−0.9887NS	1.6405NS
RS hybrid	12.8095**	1.8895**	12.9784**	0.2369NS	−1.3822NS	0.6233NS
Perennial ryegrass	0.8762NS	2.1465**	1.6341NS	2.3291NS	−0.0480NS	−0.9652NS

* Indicates significance at $P = 0.05$.
** Indicates significance at $P = 0.01$.
† Each irrigation level was considered as an environment. Species × replication × irrigation level means were used as raw data for analysis.
‡ Fifteen environments were created by making appropriate combinations from three years and five irrigation levels.
§ Each year was considered as an environment. Species × replication × year means were used as raw data for analysis.

hybrid and smooth brome had low phenotypic variances across IL (Table 2). A low phenotypic variance, which is a measure of homeostasis or biological stability (Lin et al., 1986), indicates that forage yield of these species did not respond in a similar fashion as higher-yielding species to the increasing irrigation. Classifying RS hybrid as biologically stable is further supported by s_i^2 remaining significant even after the removal of the linear effect of irrigation (Table 3).

Tall fescue, orchardgrass, and meadow brome were selected on a mean-yield basis and by the YS_i index (Table 4). Therefore, selection on mean yield was as efficient as the YS_i index for selection of species that were stable across IL. In addition to the above three species, the KRS index also included brome hybrid at a cost of reducing mean yield by 5.6% (Table 4). The most liberal index, KMRS, included perennial ryegrass as a fifth species resulting in a 12.8% yield reduction (Table 4). These yield reductions represent the opportunity cost of using more stable species that in theory guard against the possibility of limited or unreliable irrigation.

Species Stability and Selection across Irrigation Levels and Years

The Shukla's stability statistics for the species × IL × year interaction were estimated using the 15 IL-year combinations. According to Shukla's stability-variance statistic, orchardgrass, and perennial ryegrass did not contribute to the overall species × environment interaction (Table 3). While we were surprised that perennial ryegrass was judged to be stable over all environments, the overriding effect of irrigation, as discussed above, most likely resulted in its apparent stability. The σ_i^2 of all other species was significant, with that for Matua brome being largest in magnitude (Table 3).

The use of the environmental index as a covariate resulted in nonsignificant s_i^2 for smooth brome and RS hybrid, as well as orchardgrass and perennial ryegrass (Table 3). The change in significance between σ_i^2 and s_i^2 for smooth brome and RS hybrid indicates that the linear effect of the environment was the underlying cause of these species instability. Kang et al. (1991) state "the environmental index measures differences in the effects of fertility and/or cultural practices." In this

Table 4. Species selected on the basis of mean annual dry matter yield, Kang's rank sum index (KRS), Kang's modified rank sum index (KMRS), and Kang's yield-stability statistic (YS_i) using five irrigation levels as environments and mean yield across years as raw data.†

	Yield			KRS				KMRS			YS_i			
Species	Yield Mg ha^{-1}	Yield rank (Y)	Yield select	σ_i^2‡	σ_i^2 rank (S)	Rank Sum (Y+S)	KRS select	Stability rating (SR)§	Sum Y+SR	KMRS select	Adj. to Yield rank¶	Adj. Yield rank (YA)	Sum YA+SR	YS_i select
Tall fescue	19.6	8	x	1.8917**	5	13	x	−8	0	x	+3	11	3	x
Meadow brome	17.3	7	x	0.3959NS	8	15	x	0	7	x	+3	10	10	x
Orchardgrass	17.0	6	x	4.4165**	4	10	x	−8	−2	x	+3	9	1	x
Matua brome	14.3	5		15.6686**	1	6		−8	−3		−1	4	−4	
Brome hybrid	13.9	4		1.5128*	6	10	x	−4	0	x	−2	2	−2	
Smooth brome	12.6	3		6.3687**	3	6		−8	−5		−3	0	−8	
RS hybrid	11.5	2		12.8095**	2	4		−8	−6		−3	−1	−9	
Perennial ryegrass	10.6	1		0.8762NS	7	8		0	1	x	−3	−2	−2	
LSD (0.05)	0.4													
Yield and index means	14.6		18.0			8.25	17.0		−1.00	15.7			−1.38	18.0
Yield change (%)#							−5.6			−12.8				0.0

* Indicates significance at $P = 0.05$.
** Indicates significance at $P = 0.01$.
† Species with yield or index values equal to or greater than the mean yield or index value were selected.
‡ Shukla's (1972) stability-variance statistic.
§ Stability rates assigned as −8, −4, and −2 for σ_i^2 significant at $P = 0.01$, 0.05, and 0.1, respectively; and 0 for nonsignificant σ_i^2.
¶ Adjustment of +1 for mean yield > overall mean yield (OMY), +2 for mean yield ≥ 1 LSD above OMY, +3 for mean yield ≥ LSD above OMY, −1 where OMY > mean yield > 1 LSD below OMY, −2 for mean yield ≤ 1 LSD below OMY, and −3 for mean yield ≤ LSD below OMY.
\# Percent yield reduction in comparison to selection on the basis of yield alone.

Table 5. Species selected on the basis of mean annual dry matter yield, Kang's rank sum index (KRS), Kang's modified rank sum index (KMRS), and Kang's yield-stability statistic (YS_i) using year-irrigation level combinations as 15 environments.†

	Yield			KRS				KMRS			YS_i			
Species	Yield Mg ha^{-1}	Yield rank (Y)	Yield select	σ_i^2‡	σ_i^2 rank (S)	Rank sum (Y+S)	KRS select	Stability rating (SR)§	Sum Y+SR	KMRS select	Adj. to Yield rank¶	Adj. Yield rank (YA)	Sum YA+SR	YS_i select
Tall fescue	19.6	8	x	37.1681**	2	10	x	−8	0	x	+3	11	3	x
Meadow brome	17.3	7	x	13.1575**	3	10	x	−8	−1	x	+3	10	2	x
Orchardgrass	17.0	6	x	3.9013NS#	7	13	x	−2	4	x	+3	9	7	x
Matua brome	14.3	5		62.7791**	1	6		−8	−3		−1	4	−4	
Brome hybrid	13.9	4		5.9375**	5	9		−8	−4		−2	2	−6	
Smooth brome	12.6	3		5.4150**	6	9		−8	−5		−3	0	−8	
RS hybrid	11.5	2		12.9784**	4	6		−8	−6		−3	−1	−9	
Perennial ryegrass	10.6	1		1.6341NS	8	9		0	1	x	−3	−2	−2	
LSD (0.05)	0.5													
Yield and index means	14.6		18.0			9	18.0		−1.75	16.1			−1.88	18.0
Yield change (%)††							0.0			−10.6				0.0

* Indicates significance at $P = 0.05$.
** Indicates significance at $P = 0.01$.
† Species with yield or index values equal to or greater than the mean yield or index value were selected.
‡ Shukla's (1972) stability-variance statistic.
§ Stability rates assigned as −8, −4, and −2 for σ_i^2 significant at $P = 0.01$, 0.05, and 0.1, respectively; and 0 for nonsignificant σ_i^2.
¶ Adjustment of +1 for mean yield > overall mean yield (OMY), +2 for mean yield ≥ 1 LSD above OMY, +3 for mean yield ≥ LSD above OMY, −1 where OMY > mean yield > 1 LSD below OMY, −2 for mean yield ≤ 1 LSD below OMY, and −3 for mean yield ≤ LSD below OMY.
# σ_i^2 for orchardgrass significant at the 0.10 probability level, therefore stability rating equals −2 and not 0.
†† Percent yield reduction in comparison to selection on the basis of yield alone.

study, we would expect the environmental index to account for yield-potential differences due to irrigation levels, soil fertility, yearly conditions, and possible interactions among these three factors. Therefore, it is impossible to conclude exactly what underlying environmental factors were associated with smooth brome and RS hybrid's apparent instability across environments. Even though these are drought-tolerant species, IL may have contributed to the environmental effect; however, less obvious is the confounding effect of IL and possible soil nitrogen accumulation. General observation of the plots indicated that by the third year there may have been a slight nitrogen accumulation in the soil at lower irrigation levels. This was probably due to a lower rate of nitrogen leaching and plant uptake at these IL, and is consistent with multi-year experiments involving line-source sprinkler systems (D.A. Johnson, USDA Research Physiologist, personal communication). In addition, smooth brome's and RS hybrid's more homeostatic nature and lower yield potential at more favorable environments probably had some role in their deviation from the overall species response to environments.

Tall fescue, meadow brome, and orchardgrass had higher DMY than the overall mean DMY and were selected on a yield-alone basis (Table 5). Therefore, two of the three yield-based selections were unstable across environments. The KRS and YS_i selection methods selected the same three species, making them no more efficient than yield-basis selection in selecting stable species (Table 5). The KMRS method, which places

Table 6. Species selected on the basis of mean annual dry matter yield, Kang's rank sum index (KRS), Kang's modified rank sum index (KMRS), and Kang's yield-stability statistic (YS_i) using three years as environments and mean yield across irrigation levels as raw data.†

	Yield			KRS				KMRS			YS_i			
Species	Yield Mg ha^{-1}	Yield rank (Y)	Yield select	σ_i^2‡	σ_i^2 rank (S)	Rank Sum (Y+S)	KRS select	Stability rating (SR)§	Sum Y+SR	KMRS select	Adj. to Yield rank¶	Adj. Yield rank (YA)	Sum YA+SR	YS_i select
Tall fescue	19.6	8	x	46.3516**	2	10	x	−8	0	x	+3	11	3	x
Meadow brome	17.3	7	x	14.3157**	3	10	x	−8	−1		+3	10	2	x
Orchardgrass	17.0	6	x	−2.3973NS	8	14	x	0	6	x	+3	9	9	x
Matua brome	14.3	5		66.2938**	1	6		−8	−3		−1	4	−4	
Brome hybrid	13.9	4		5.9340**	4	8		−8	−4		−2	2	−6	
Smooth brome	12.6	3		−0.9887NS	6	9	x	0	3	x	−3	0	0	
RS hybrid	11.5	2		−1.3822NS	7	9	x	0	2	x	−3	−1	−1	
Perennial ryegrass	10.6	1		−0.0480NS	5	6		0	1	x	−3	−2	−2	
LSD (0.05)	0.6													
Yield and index means	14.6		18.0			9.0	15.6		0.50	14.3			0.13	18.0
Yield change (%)#							−13.3			−20.6				0.0

* Indicates significance at $P = 0.05$.
** Indicates significance at $P = 0.01$.
† Species with yield or index values equal to or greater than the mean yield or index value were selected.
‡ Shukla's (1972) stability-variance statistic.
§ Stability rates assigned as −8, −4, and −2 for σ_i^2 significant at $P = 0.01$, 0.05, and 0.1, respectively; and 0 for nonsignificant σ_i^2.
¶ Adjustment of +1 for mean yield > overall mean yield (OMY), +2 for mean yield ≤ 1 LSD above OMY, +3 for mean yield ≤ LSD above OMY, −1 where OMY > mean yield > 1 LSD below OMY, −2 for mean yield ≥ 1 LSD below OMY, and −3 for mean yield ≥ LSD below OMY.
# Percent yield reduction in comparison to selection on the basis of yield alone.

more emphasis on stability, included perennial ryegrass in the selected species, but at a cost of reducing selected-species mean yield by 10.6% (Table 5).

Species Stability and Selection across Years

Orchardgrass, smooth brome, RS hybrid, and perennial ryegrass were identified as being stable across years (Table 3). Heterogeneity (or nonadditivity) caused by the environmental index was not significant for species × year (Table 1). Our observations of irrigated perennial ryegrass pastures have indicated that perennial ryegrass yield usually declines across years, with a sharp reduction after the fourth or fifth year in production. Because of the assumed nitrogen buildup at lower IL, this study was terminated and we could not confirm perennial ryegrass's yield decline with stability statistics.

As in previous cases, the species selected by the YS_i index and yield-alone basis were identical (Table 6). The KRS index included an additional two stable species, whereas the KMRS index dropped meadow brome and selected perennial ryegrass resulting in an unacceptable yield reduction of 20.6%.

In conclusion, we found that Shukla's stability variance statistics and Kang's YS_i and KRS yield-stability selection indices were practical, informative, and useful. Decisions using these statistics should be based knowing that Shukla's stability measures deviations from the overall mean response, and as such, are not necessarily equivalent to homeostasis-based stability (Lin et al., 1986). Therefore, inference is limited unless the evaluated genotypes accurately represent genotypes grown in the test environments (Lin et al., 1986). We would recommend using the YS_i index to simultaneously select for yield and stability. The KRS index would be useful when slightly more emphasis is wanted on stability. We felt that Kang's KMRS index placed too much emphasis on stability resulting in unacceptable yield reductions. Overall, these stability indices may be better suited for selection of genotypes within a species where the range of yield values is less than we observed. Given our range of IL and years, selection on yield-only basis efficiently (correctly) identified the species of choice for intensively grazed, irrigated pastures in the Intermountain west. We agree with Jensen et al. (2001) that tall fescue, orchardgrass, and meadow brome are the species of choice for irrigated, intensively grazed pastures where water may be limited and DMY is the primary selection criteria. Whereas Jensen et al. (2001) made their recommendations only on the basis of mean DMY, we have shown meadow brome and orchardgrass should be selected not only because of their yield potential, but also their stability across IL and combined year-IL environments, respectively. Tall fescue should be selected because of its superior yield potential across the tested range of irrigation levels. Other species in this paper may be better suited to levels of grazing management and irrigation not tested.

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